Frequency stabilization of a Helium-Neon laser using a microcontroller

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Introduction

Frequency-stabilized internal-mirror Helium-Neon lasers are essential as light sources for high accuracy laser interferometry. A He-Ne laser is coherent for a much longer range compared to a regular laser diode, extending its range of use. For example, good long laser beam coherence allows us to keep a high frequency amplitude when we have a setup on a long table (interferometers).

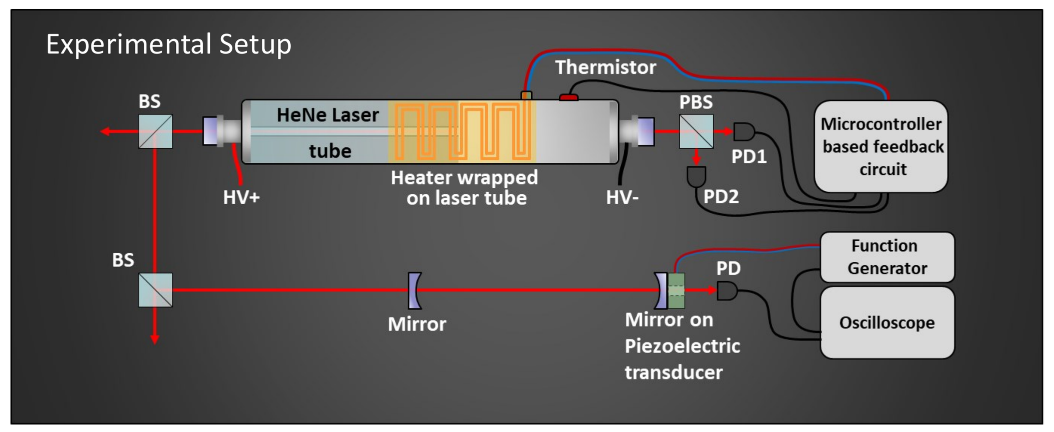
One issue with these lasers though is that the power and frequency of the beam tends to fluctuate due to mostly thermal instabilities that cause changes in the length of the laser tube. However, it can be automated using a microcontroller, adjust the position of the S and P polarization on the lasing output power curve in order to make them equal on opposite ends [1-3].

Once stabilized it can be used in applications such as wavelength and vibrational metrology, it also serves as the backbone for stabilization of interferometers used for the study of coherence properties of light [4-5].

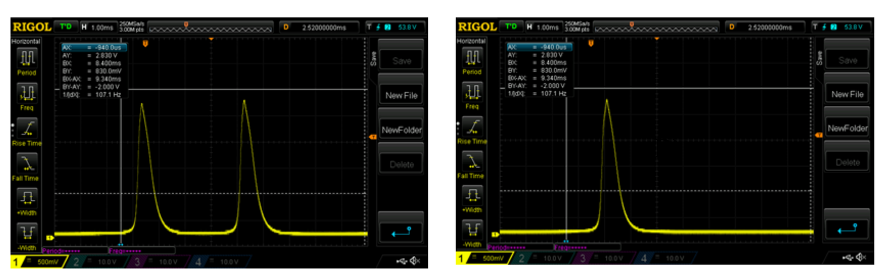
Methods

We built a He-Ne laser with active feedback for a single frequency operation.

- A flexible heating element wrapped around the laser tube.
- A thermistor was used for the reading of the temperature.
- The microcontroller brought the laser tube to the optimal temperature.
- Once at set temperature, microcontroller switches to frequency control mode.
- It then forces the frequency to propagate in two orthogonally polarized modes with equal amplitudes.
- Finally, we analyzed single frequency operation using a Fabry Perrot etalon that we assembled in order to operate it as a diagnostic instrument.



Observation of the S and P polarization modes

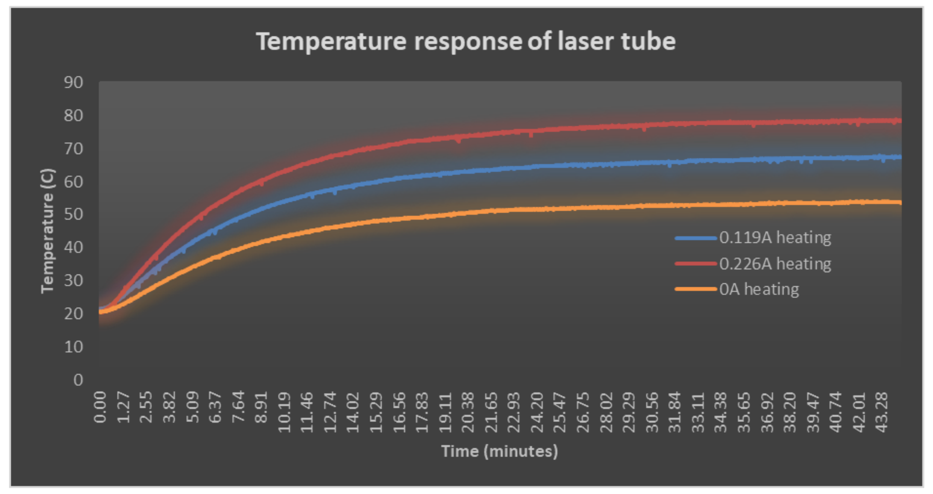


A) S-P polarization modes, without polarization selection
B) S polarization mode only after introducing a polarizer that eliminates the P mode.

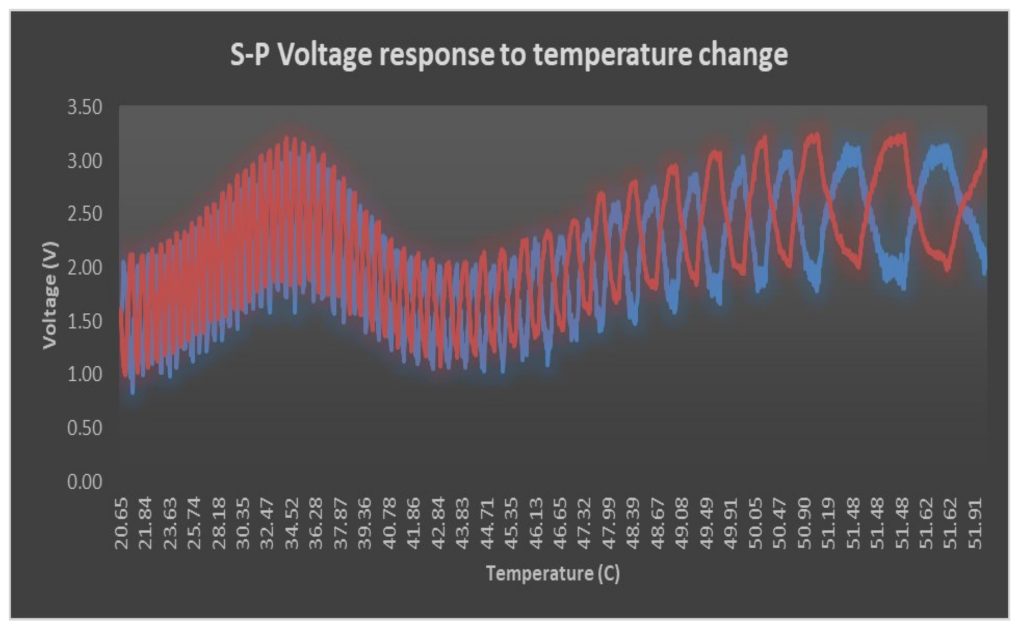
- We have confirmed that our Helium Neon laser does indeed only have 2 polarization modes (1S and 1P) in order to continue working with it.
- This was done using the Fabry Perrot etalon.

Temperature and frequency behavior

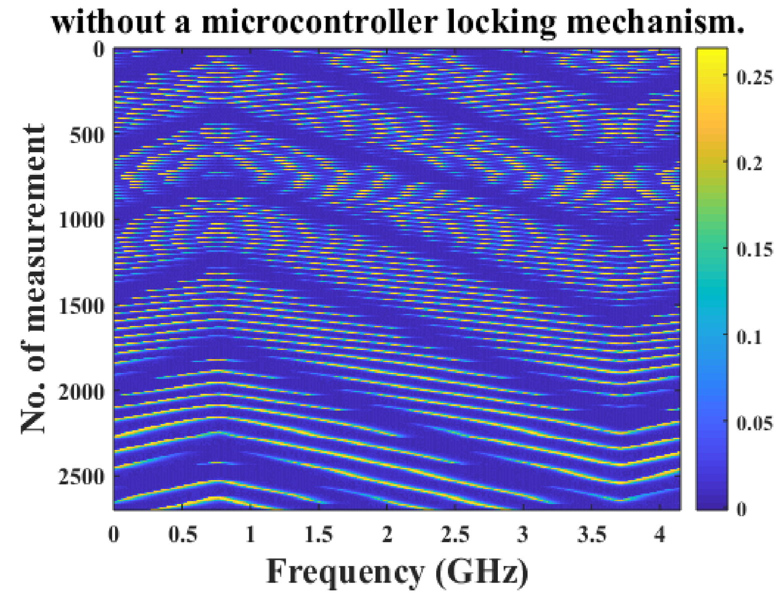
- **Temperature response.**
- We use a MOSFET to drive the heater.
- The current control happens trough the microcontroller.
- The current control is done with Pulse-Width-Modulation.



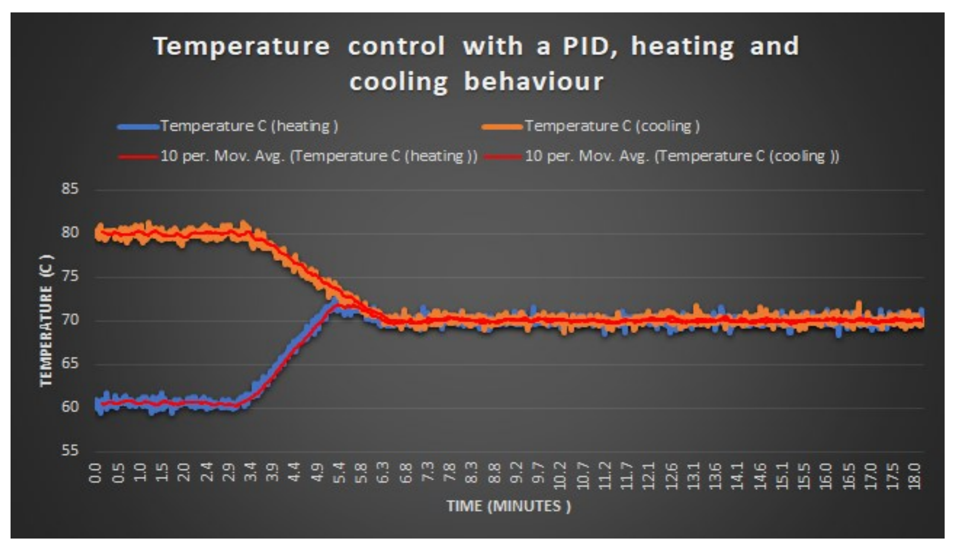
- **Frequency response to changes in temperature.**
- Here we recorded the (Red-Blue) S-P Intensity (converted to voltage) response to temperature change.
- As the temperature increases the length of the laser tube increases and that changes the frequency of the S and P modes leading to an intensity oscillation.
- Using the difference between the 2 modes, we determined the desired setpoint for frequency locking.



S-P mode behaviour without a microcontroller locking mechanism.

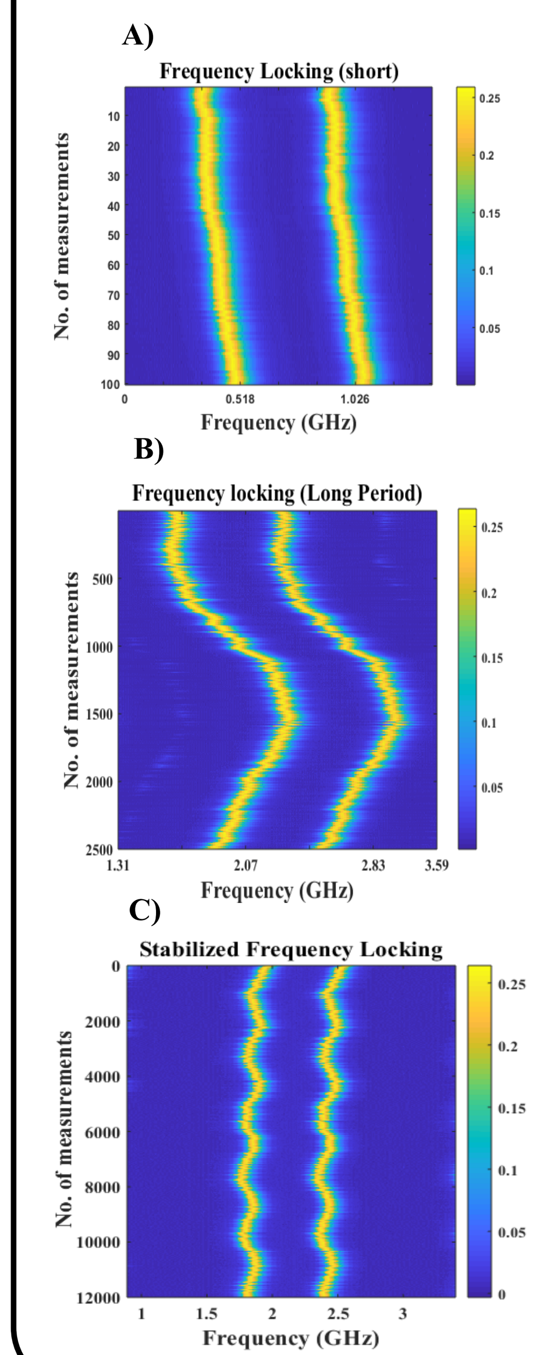


PID Temperature control



- We tuned the PID parameters.
- Used PID microcontroller to reach the setpoint temperature.
- The recorded behavior shows that the temperature control has the same response time,.
- Cooling happens in a smooth way.
- Heating is usually followed with an overshoot.
- Timescales are very similar.

Frequency Stabilization



- The Doppler width of a Helium Neon transition is 1.5 GHz.
- 0.588 GHz equates 1 mode spacing in our particular setup. [1]
- Our laser cavity is 255mm long, fitting only 2 and a half modes.
- Using the developed PID mechanism, we switched the microcontroller to frequency locking mode.
- As seen in A), initially the 2 modes are locked and stable.
- However over time they start drifting and oscillating (B)), this is due to local disturbances and unstable PID values
- Further P-I-D parameter tuning was carried.
- Once the stable parameters were found, we took a long measurement (2 hours) to test the stability.
- As seen in C), the 2 frequency modes do not drift and stay locked for the duration of the 2 hours.
- The Helium-Neon laser is now ready to be used in further metrology work.

Future work

The stabilized Helium-Neon laser can now be used in future experiments and work, such as:

- Metrology
- Alignment
- Semiconductor inspection
- High-speed printing & reprographics

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